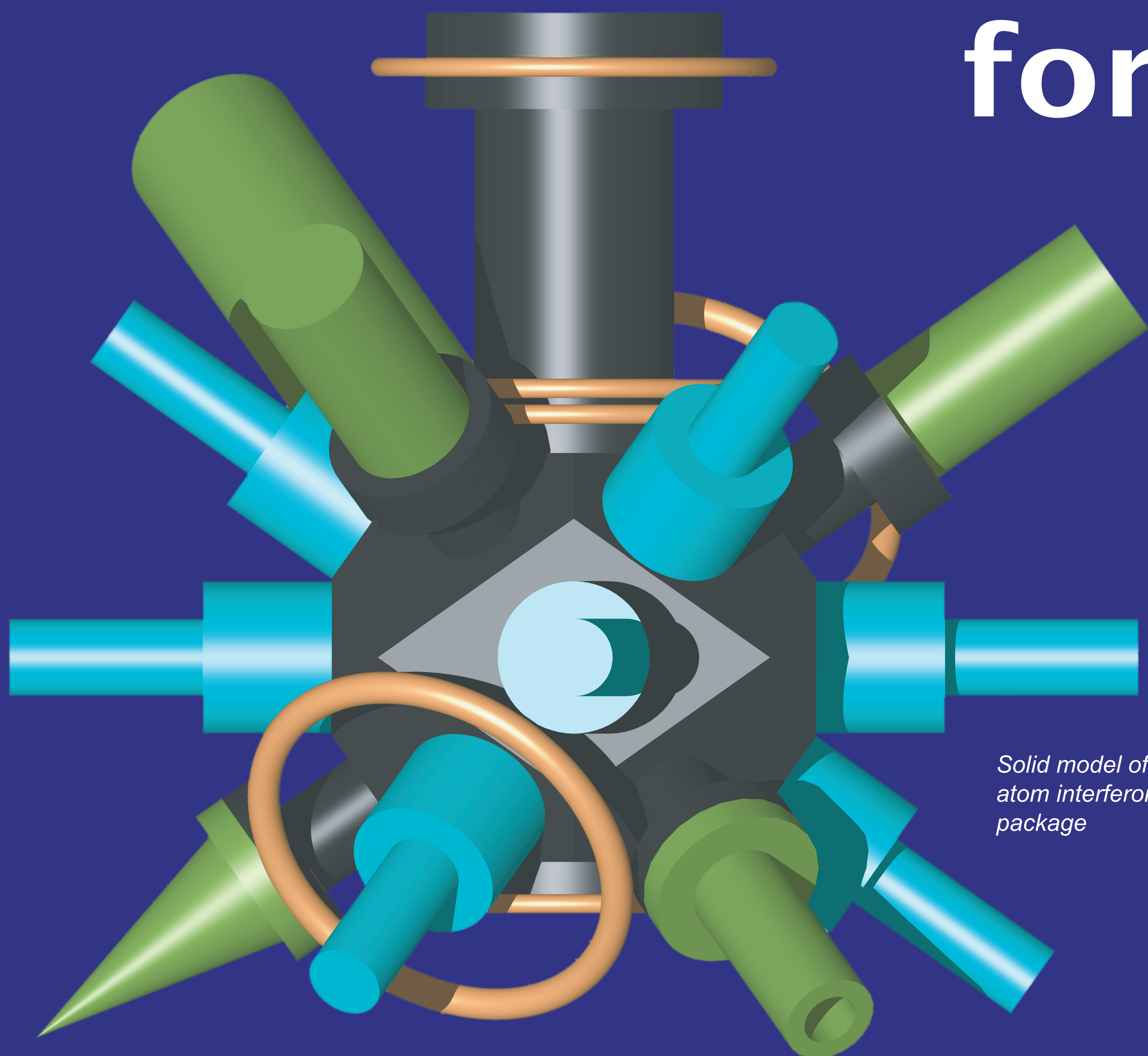
Earth Science Technology Office (*ESTO)*

Quantum Gravity Gradiometer

for Sub-Surface Mapping

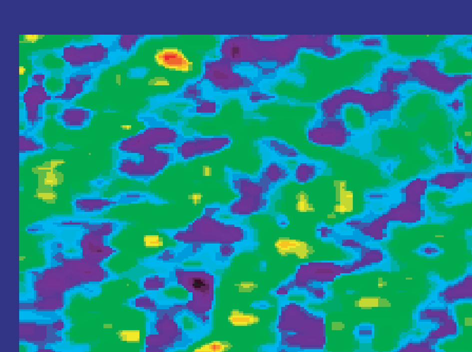


Solid model of laboratory atom interferometer physics package

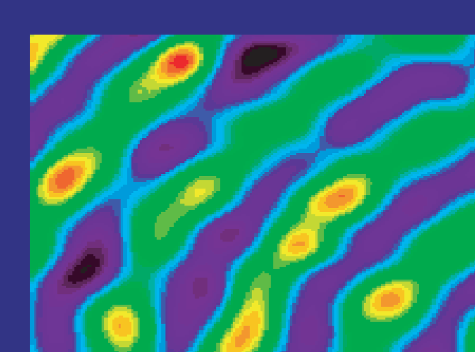
Imagine a global map that fully characterizes Earth's subterranean features--caverns, mineral deposits, faults, water tables, and so on. Imagine monitoring sub-surface features over time--from the thickness of ice sheets to the shifting of tectonic plates--from the vantage point of space. This may all be made possible with the help of a flyable quantum gravity gradiometer that utilizes atom interferometry.

Recent advances in laser cooling and atom manipulation have made atom interferometers a realistic option for gravity measurements. The fundamental concept behind atom interferometry is the quantum mechanical particle-wave duality. One can exploit the wave-like nature of atoms to construct an atom interferometer based on matter waves analogous to laser interferometers. Because of the finite mass of the atom, atom wave interferometers are extremely sensitive to gravity. This advantage can be appreciated by the fact that the atom interferometer has an inherent inertial-sensing sensitivity that is more than 10 orders of magnitude (the ratio of the atomic mass and photon energy) greater than an equivalent laser interferometer.

A "toy" model of ocean bottom pressure horizontal structure



Horizontal distribution of gravity gradient data, taken from one month of passes by a polar orbiter at 200km altitude



Reconstruction of the sources by deconvolution

HOW IT WORKS

Cesium atoms are first collected and cooled by lasers into a small cloud in a magneto-optic trap (MOT). The MOT, consisting of three pairs of counter-propagating laser beams along three orthogonal axes centered on a non-uniform magnetic field, collects up to 10^9 atoms from a beam or a background vapor. After these atoms are collected, further laser-cooling brings the atoms' temperature down to a couple of μK, corresponding to an rms velocity of a few cm/s. These temperatures are cold enough so that the wave nature of atoms can be exploited, and laser beams with appropriate wavelengths can perform reflection and beam splitting functions with the atoms. In a terrestrial application, the cold atoms are launched vertically to achieve twice the available interaction time in an apparatus of given height. Atom wave interferometry is then performed during the subsequent free fall of atoms in this "atomic fountain". In the environment of space, the totally drag-free atoms allow much longer interaction times, and therefore much improved gravity measurement sensitivity.

In the gradiometer instrument, two acceleration measurements are performed simultaneously on two atom interferometers separated by a fixed distance using the same laser beams. By measuring the difference between the two acceleration values, the common-mode noises are effectively eliminated.

FUTURE APPLICATIONS

- Sub-surface mapping and dynamics
- Ice sheet and ocean current variability monitoring
- Water table and storage observation
- Natural resources exploration
- Comprehensive geodesy studies

FEATURES & BENEFITS

- Exceptional sensitivity to variations in gravity
- Exceptional spatial resolution
- Multi-component gravity tensor measurement
- Temporal monitoring
- Long term stability and accuracy
- Single spacecraft based operation
- No cryogenics

ACKNOWLEDGEMENTS

- Funding by ESTO, the Earth Science Technology Office at NASA
- TEAM MEMBERS: Lute Maleki, Jet Propulsion Laboratory; Nan Yu, Jet Propulsion Laboratory; James M. Kohel, Jet Propulsion Laboratory; Larry Romans, Jet Propulsion Laboratory.